



Forest Health Protection

Pacific Southwest Region

Northeastern California Shared Service Area

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To: District Ranger, Yuba River Ranger District, Tahoe National Forest

Subject: Evaluation of stand conditions with respect to forest insects and diseases within the Trapper Project, Tahoe National Forest (FHP Report NE19-03)

At the request of Roger Brown, Silviculturist, Yuba River Ranger District, Danny Cluck, Forest Health Protection (FHP) Entomologist, visited the Trapper project on July 30, 2019. The objective of this visit was to evaluate current stand conditions, determine the impacts of forest insects and diseases on management objectives and discuss proposed alternatives. Recommendations provided in this report will assist in the formulation of silvicultural prescriptions aimed at reducing stand density and increasing resiliency to fire, insects and diseases.

Key Findings

- High stand density is putting many stands at risk to increased levels of bark beetle-caused tree mortality during periods of drought. Many of these stands are also at risk to high severity wildfire.
- Ponderosa pine plantations are overstocked and at risk to high levels of tree mortality caused by western pine beetle (Figure 1).
- White pine blister rust is infecting sugar pine, increasing the susceptibility of mature trees to bark beetle attack and negatively impacting regeneration.
- Native mixed conifer stands have experienced elevated levels of ponderosa and sugar pine mortality caused by western pine beetle and mountain pine beetle.
- Elevated white fir mortality associated with fir engraver beetle was mapped by aerial survey within the project area in 2018.
- Thinning and prescribed fire are highly recommended throughout the project area to reduce tree density and reduce surface and ladder fuels. The treatments proposed by the District are supported by FHP. Additional recommendations are provided in this evaluation.

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Figure 1. Dense ponderosa pine plantation within Trapper project area.



Description of the project area

The Trapper project is centered approximately 4 miles east northeast of Camptonville, CA (39.476965N and 120.981116E). The elevation ranges from 2,000 – 5,200 feet with annual precipitation ranging between 50 and 75 inches. Most of the area is comprised of Sierra mixed conifer consisting of Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), incense cedar (*Calocedrus decurrens*), white fir (*Abies concolor*), California black oak (*Quercus kelloggii*), Pacific madrone (*Arbutus menziesii*), and tanoak (*Notholithocarpus densiflorus*). Ponderosa pine dominated stands are found on south and west facing slopes, ridgetops and drier valley bottoms often mixed with black oak, tan oak, incense cedar and Douglas-fir. The project area also includes large, 60-year-old ponderosa pine plantations.

Management objectives

The Trapper project proposes to reduce hazardous fuels and stand density through commercial and precommercial thinning, mastication of brush and prescribed burning. Native ponderosa pine stands and plantations will be thinned to approximately 80-100 sq. ft./acre of basal area emphasizing stand and species variability. Mixed conifer stands will retain relatively higher stocking (~140-180 sq. ft./acre), especially in California spotted owl habitat, but emphasize density reduction in overstocked groups of ponderosa pine, California black oak release, a reduction in shade tolerant tree species, and removing smaller diameter trees from the understory. The residual stands will be more open, increasing the amount of available soil moisture and sunlight for individual trees and reducing the risk to high severity wildfire. Hazard trees will be identified and removed along all roadways.

Forest insect and disease conditions

Agents observed:

- Older pockets of western pine beetle (*Dendroctonus brevicomis*)-caused mortality of ponderosa pine that occurred during the recent drought.
- Recent top-killing of a few ponderosa pine by California fivespined ips (*Ips paraconfusus*) near Brush Creek Ridge.
- White pine blister rust (*Cronartium ribicola*) in sugar pine causing top-kill and whole tree mortality of all size classes, often in combination with mountain pine beetle (*Dendroctonus ponderosae*) (Figure 2).
- Scattered white fir mortality caused by fir engraver beetle and possibly Heterobasidion root disease (*Heterobasidion occidentale*). No inspections were made to confirm root disease presence.

Stand conditions and mortality related to recent and future climate trends

Many of the forested areas in the Trapper project are in an overstocked condition and some areas have experienced a high level of tree mortality caused by bark beetles during and since the recent drought (Table 1 and Figures 3 - 6). Ground surveys

Figure 2. Sugar pine killed by white pine blister rust and mountain pine beetle near Brush Creek Ridge.



Figure 3. Western pine beetle-caused mortality in dense ponderosa pine plantation within Trapper project area. FHP Aerial Detection Survey 2016.



Figure 4. Western pine beetle-caused mortality of ponderosa pine stands within Trapper project area. FHP Aerial Detection Survey 2016.



Table 1. Acres with tree mortality, estimated dead trees per acre, estimated total # of dead trees from R5 Aerial Detection Surveys and Palmer Hydrologic Drought Index (PHDI) (CA Division 2) by water year (Oct-Sept) within the Trapper Project.

Year	Acres	Dead Trees/Acre	Total # of Dead Trees	PHDI ¹
2018	3,746	3.7	14,027	-1.87
2017	2,562	5.2	13,314	2.49
2016	6,137	5.0	30,547	-1.78
2015	367	9.5	3,475	-3.03
2014	72	1.2	89	-3.12
2013	202	2.3	460	-1.62
2012	214	1.5	326	0.37
2011	100	1.0	102	2.59
2010	285	1.7	480	0.19
2009	265	3.1	822	-2.69

¹ Palmer drought values show a relationship to tree mortality. PHDI values ranging from -2.00 to -2.99 are considered moderate drought conditions. Severe drought conditions range from -3.00 to -3.99 and extreme drought conditions are below -4.00.

identified a sharp increase in ponderosa pine mortality for the project and surrounding areas during 2016 after the extremely dry water year of 2014 and 2015 (see FHP Report NE16-02). Elevated levels of bark beetle-caused tree mortality in the project area, as well as in the rest of the Sierra Nevada range, are strongly associated with periods of below normal precipitation and high stand density. This mortality combined with the existing high stand density has resulted in heavy fuel loading in some areas and a corresponding increase in the risk of stand replacing wildfire.

Figure 5. Extent of white fir, ponderosa pine and Douglas-fir mortality in 2018 as detected by ADS flight.

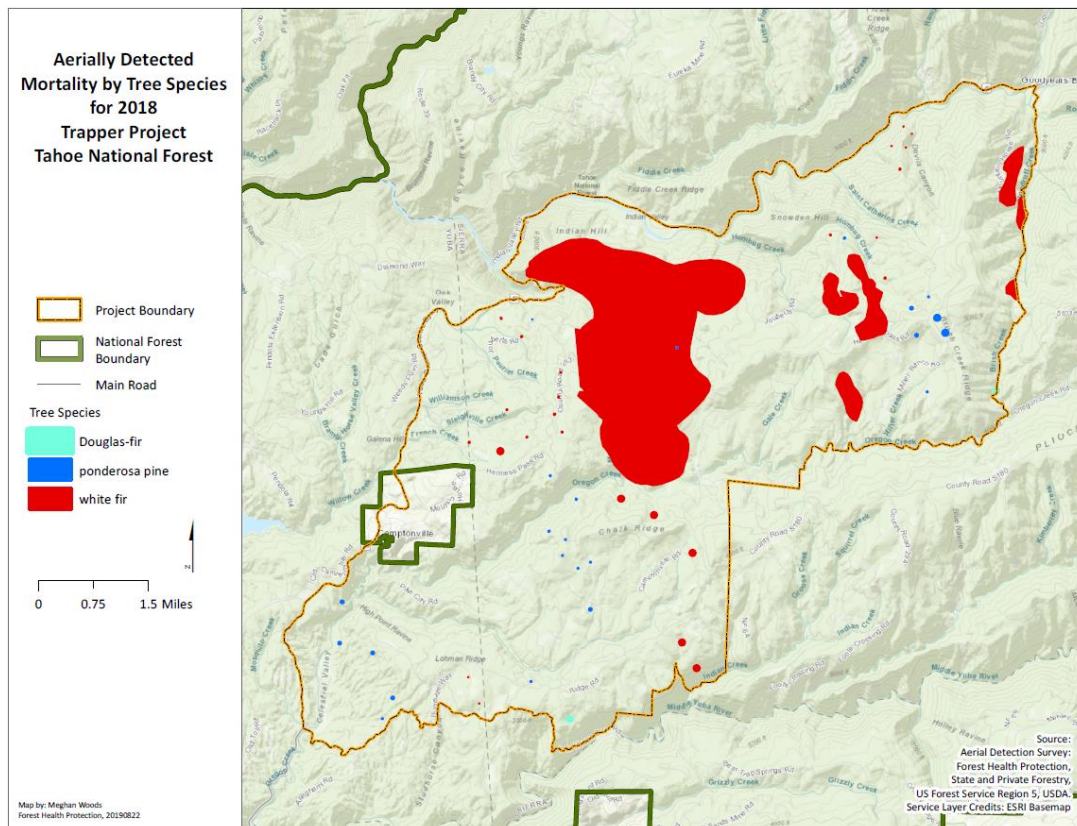
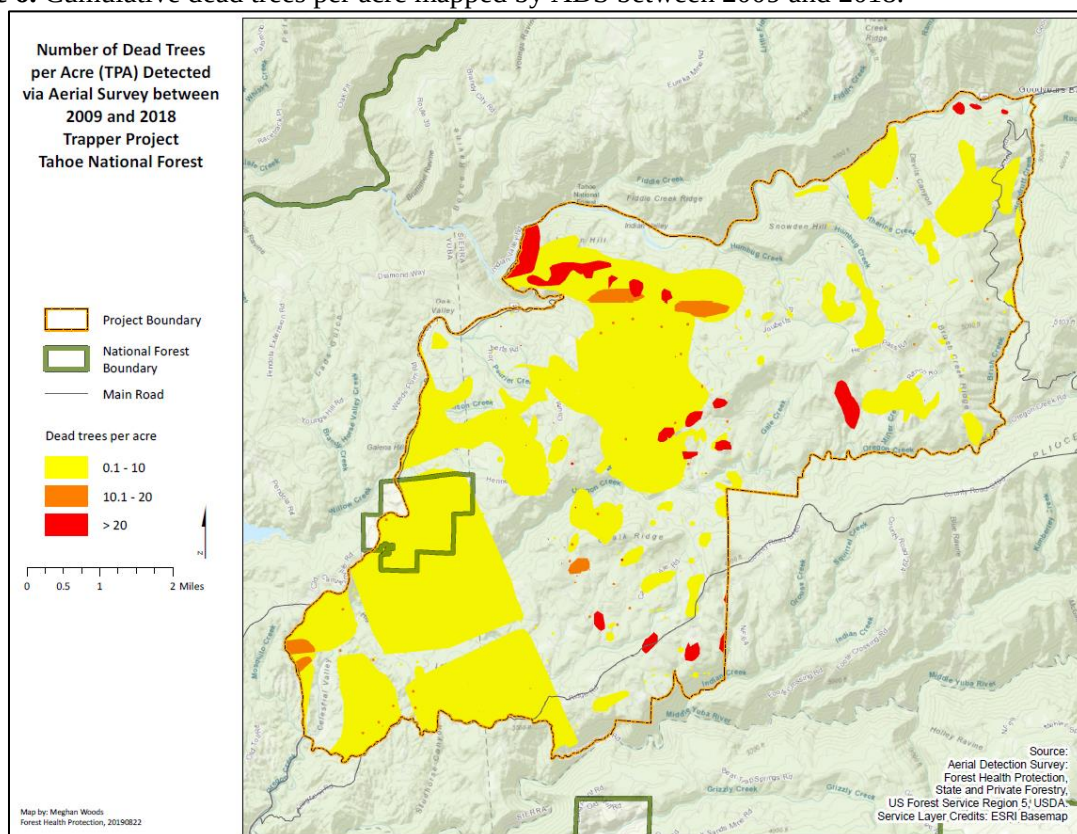


Figure 6. Cumulative dead trees per acre mapped by ADS between 2009 and 2018.



Forest Health Protection recently developed a treatment priority map for Region 5 to help land managers prioritize thinning treatments at the landscape level. This map depicts forested areas on National Forest System lands that are the most susceptible to drought and bark beetle-caused tree mortality based on forest type and stand density. These areas also meet the criteria of existing on slopes $\leq 35\%$ and being outside of wilderness areas, wild and scenic river corridors and designated roadless areas. Additional criteria include not having burned at moderate to high severity since 1998 and not having been thinned since 2005. In addition to being overly dense, these areas have a history of tree mortality during drought resulting in heavy fuel loads and higher risk of stand replacing wildfire. Highest priority areas consist of high density pine stands, pine-dominated mixed conifer stands, and fir-dominated mixed conifer and white fir stands growing on historically pine dominated sites. Second priority areas consist of high density fir-dominated mixed conifer and white fir stands on wetter sites. All mapped stands are California Wildlife Habitat Relationship size class 4, 5 and 6.

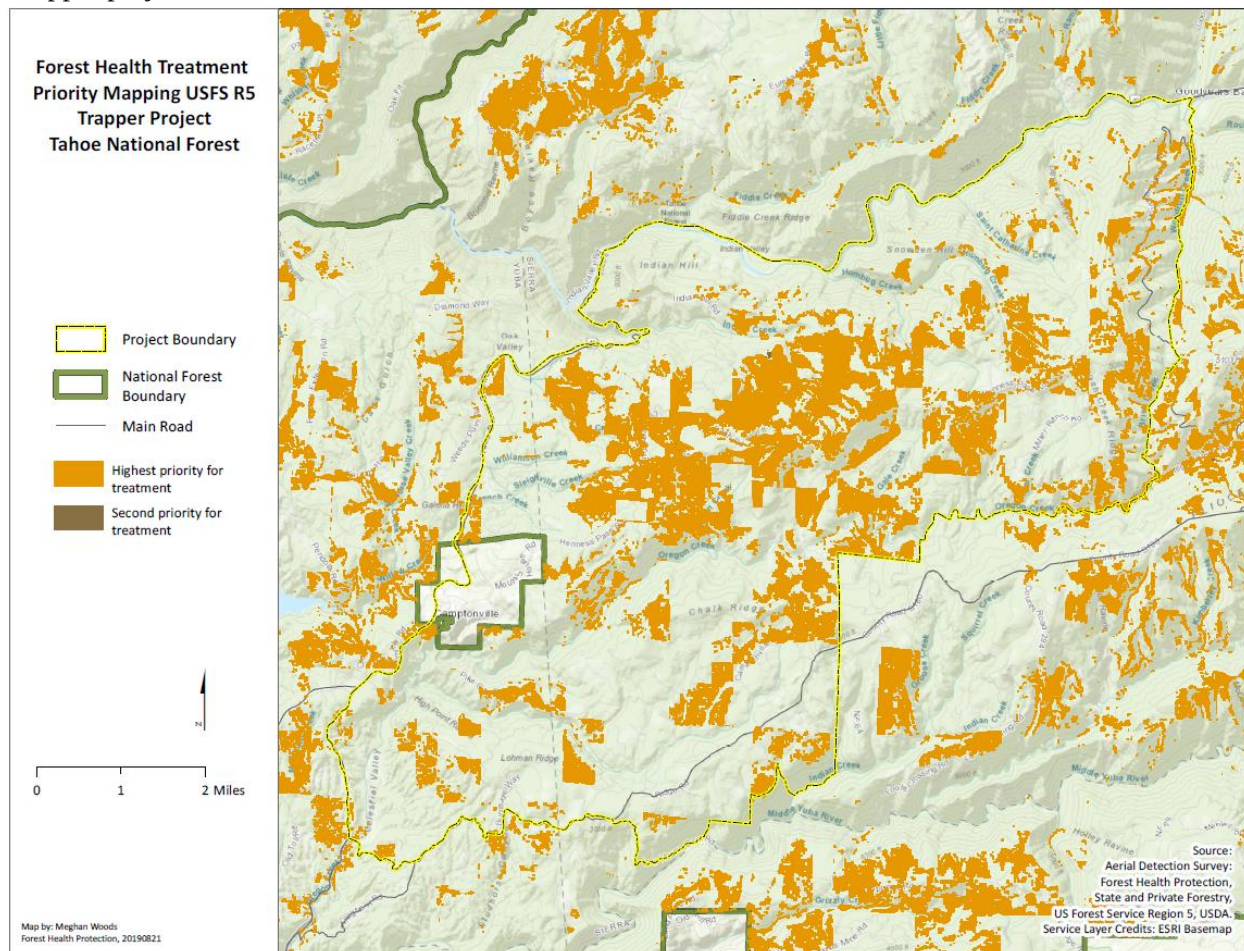
Figure 7 shows treatment priority areas within the Trapper project boundary. This mapping effort utilized remotely sensed data to create treatment priority layers for large scale planning and may not be accurate at the stand level. The forest should still use stand records and stand exam data to identify treatment areas and develop silvicultural prescriptions. An ALL LANDS version of the map was also created that includes wilderness areas, wild and scenic river corridors designated and roadless areas to evaluate stand conditions in these protected areas. It also includes slopes $> 35\%$ and all land ownerships (Figure 8).

Predicted climate change is likely to impact trees growing in this area over the next 100 years. Although no Tahoe National Forest specific climate change models are available at this time, there is a consensus among California models that summers will be drier than they are currently. This prediction is based on the forecasted rise in mean minimum and maximum temperatures and remains consistent regardless of future levels of annual precipitation (C. Mallek and H. Safford, *A summary of current trends and probable future trends in climate and climate-driven processes in the Eldorado and Tahoe National Forests and neighboring Sierra Nevada*). The risk of bark beetle-caused tree mortality will likely increase for all conifer species under this scenario, especially drought intolerant and root diseased white fir and overstocked stands of larger ($> 8''$ DBH) ponderosa pine growing on lower elevation, warmer sites. Improving the resilience of the Trapper project area to future disturbance events through density, size class and species composition management will be critical to maintaining a healthy forested landscape.

Discussion and recommendations

Ponderosa pine mortality caused by western pine beetle is probably the primary threat to forest health in the Trapper project second only to wildfire. Ponderosa pine growing in high density stands in this area are at a much higher risk to large scale mortality than the other conifers due to the trees susceptibility to an aggressive bark beetle species, western pine beetle, that can build up large populations over a short time period in response to drought. Therefore, ponderosa pine should be given special consideration when planning thinning treatments to reduce its susceptibility to successful western pine beetle attacks. In native mixed conifer stands, susceptibility could be decreased by reducing density to lower levels in ponderosa pine dominated pockets (< 120 sq.ft./acre recommended) than what is appropriate for surrounding mixed conifer stands. Including the removal of suppressed individuals as well as any bark beetle infested trees will improve the efficacy of treatments. Sufficiently lowering the basal area in pine

Figure 7. Treatment Priority Areas* at risk to bark beetle-caused mortality within and adjacent to the Trapper project area



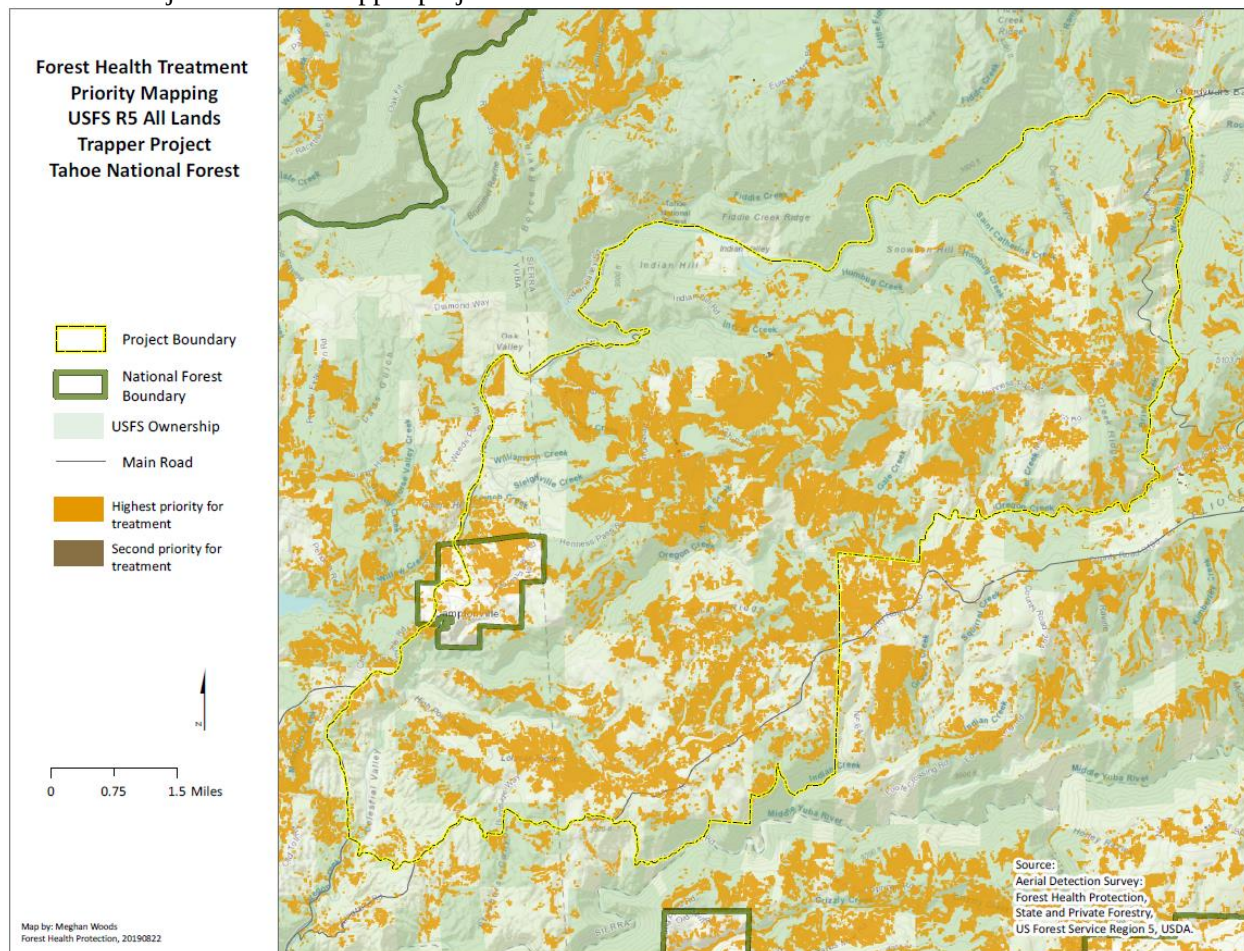
*Highest priority treatment areas include overly dense stands (>60% of maximum stand density index) of pine and pine-dominated mixed conifer stands as well as fir-dominated mixed conifer and white fir stands growing on historically pine-dominated sites. Second priority treatment areas include overly dense stands of fir-dominated mixed conifer and white fir. Mapped areas only include CWHR size class 4, 5 and 6 stands. Wilderness areas, inventoried roadless areas, wild and scenic areas, moderate to high severity burned areas since 1998, areas thinned since 2005, areas with >35% slope and all non-National Forest System lands were excluded from this analysis.

dominated pockets may reduce their canopy cover to below required thresholds. However, more basal area, and higher canopy cover, could be retained in adjacent mixed conifer areas to maintain a higher average throughout a stand.

High stand density combined with drought conditions cause extreme moisture stress in individual trees, thus reducing their ability to fend off bark beetle attacks. Healthy ponderosa pines defend themselves by producing resins that drown attacking beetles. When trees are stressed, resin pressure is reduced, and the probability of successful bark beetle attack is increased. High stand density may also improve conditions for the bark beetle pheromone communication system, which facilitates mass attacks on individual trees and groups of trees, by concentrating the pheromone plume under a full canopy.

The best strategy to decrease the amount of mortality in the long-term is to reduce stand density

Figure 8. Treatment Priority Areas (ALL LANDS version)* at risk to bark beetle-caused mortality within and adjacent to the Trapper project area.



*Highest priority treatment areas for ALL LANDS version include overly dense stands (>60% of maximum stand density index) of pine and pine-dominated mixed conifer stands as well as fir-dominated mixed conifer and white fir stands growing on historically pine-dominated sites. Second priority treatment areas include overly dense stands of fir-dominated mixed conifer and white fir. Mapped areas only include CWHR size class 4, 5 and 6 stands. Moderate to high severity burned areas since 1998, areas thinned or that experienced stand replacing disturbance such as clear cuts or bark beetle-caused tree mortality since 2005 were excluded from this analysis.

through thinning. Thinning will increase the health and vigor of residual ponderosa pines by reducing competition for limited soil moisture (Fettig et al. 2007). The District should consider reducing the SDI in ponderosa pine dominated stands to below 230. SDI 230 is the defined threshold for the zone of imminent bark beetle caused mortality. Within this zone, endemic populations kill a few trees, but net growth is still positive (Oliver 1995). Thinning stands below this level will reduce the risk of additional bark beetle-caused mortality by reducing tree competition for limited water and nutrients.

Dense ponderosa pine plantations would benefit by the same reductions in stand density with an emphasis placed on creating spatial heterogeneity and enhancing conditions for other tree species such as Douglas-fir, incense cedar and black oak. Thinning prescriptions should aim to reduce basal area to a range of 60 to 120 sq.ft./acre. This should effectively reduce the risk of significant western pine beetle-caused mortality.

It is important when thinning pine stands to be aware of the potential for pine engraver beetle (*Ips paraconfusus*) populations to increase in green slash. Ips populations can build up within green pine slash (>4" in diameter) in the spring and successfully attack and kill adjacent pines later in the summer. Mortality to residual pines from Ips beetle attacks in California have mostly been associated with green slash in the form of doodle piles or small hand piles that are left scattered throughout the stand near residual trees. The risk of subsequent tree mortality increases with drier than normal conditions and when the green material is longer in length and/or is of a larger diameter that can prevent rapid drying.

Normally, green pine slash, doodles and/or hand piles created from July through early fall (mid-October) will not be conducive to significant Ips population build up. Also, based on past observations of pine engraver beetle activity in the Sierra Nevada and Cascade mountain ranges, having pine slash, biomass and sawlogs consolidated into large piles at landings has not resulted in subsequent tree mortality, regardless of timing. If harvest activities are to occur from late fall through early summer (November-June), any green pine material should be removed from the stand, treated (chipping or burning) or consolidated onto landings by the following spring.

The presence of Heterobasidion root disease in white fir should be considered when developing silvicultural prescriptions. Root diseased true fir are at a higher risk for fir engraver attacks than uninfected trees during droughts. Leaving high numbers of root diseased trees in the overstory will likely lead to higher levels of mortality over the long-term, reducing canopy cover and increasing fuels. Leaving these trees will also reduce opportunities for successful regeneration of shade intolerant species that are not susceptible hosts to *H. occidentale*.

The best option for managing *H. occidentale* in white fir is to reduce its overall abundance in the stand and remove severely infected trees (based on declining crown characteristics). Various sized openings can be created in the stand to facilitate planting of non-hosts such as ponderosa and sugar pine. Placing these openings on known or suspected root disease pockets will enhance the effectiveness of this strategy for reducing overall infection levels. In addition, greatly reducing white fir stocking in stands that have a non-host overstory component will allow for natural non-host regeneration and create a more resilient species composition over time.

When planning thinning treatments, it should be recognized that the target stand density is an average to be applied across the landscape and some variability may be desired. Individual high value trees, such as large mature pines and black oaks, should benefit by having the stocking around them reduced to lower levels. Areas of pure or nearly pure ponderosa pine would also benefit from lower stocking levels as well as an increase in species diversity. Allowing for denser tree spacing and pockets of higher canopy cover may be desirable around potential wildlife trees, such as forked and/or broken-topped trees, or on more mesic north-facing slopes. Incorporating the concepts of GTR 220 and 237 will address many of these issues and be consistent with Regional ecosystem restoration goals. The treatments proposed by the District are consistent with these concepts and consistent with FHP recommendations for thinning in ponderosa pine and mixed conifer stands.

It is recommended that a registered borate compound be applied to all freshly cut conifer stumps >14" dbh to reduce the chance of creating new infection centers of *Heterobasidion irregulare* (formerly 'P'-type annosus root disease) and *H. occidentale* (formerly 'S'-type annosus root disease) within the unit. This is especially important along the extensive road network that is used by the local community. Treating stumps will reduce the chance of creating new infection centers that could lead to the creation of future hazard trees.

Considerations for sugar pine

Sugar pine should be retained as much as possible during any thinning operation to preserve genetic diversity, especially suspected white pine blister rust (*Cronartium ribicola*) resistant individuals. An exception to this would be thinning suppressed trees within pure sugar pine groups to reduce inter-tree competition. White pine blister rust, a non-native pathogen, has continued to weaken and kill this species over most of its range since its introduction into the Pacific Northwest in 1910. Identification and protection of local rust resistant trees for seed collection, if not already occurring, will aid in the future planting of rust resistant seedlings. Planting selected openings created through thinning operations with rust resistant stock would help insure this species persists in the area.

Considerations for Rx fire

If prescribed fire is used as a follow-up treatment to stand thinning, it may result in unacceptable levels of tree mortality; depending on management objectives. This mortality most often occurs as a direct result of cambium or crown injury to individual trees during the fire. Mature ponderosa and especially sugar pines are susceptible to lethal basal cambium damage during prescribed burns from the heat that develops in the deep duff and litter that accumulates at their bases. These duff mounds typically burn at a slow rate with lethal temperatures, causing severe injury to the cambium which girdles the trees. To protect individual high-value large diameter pine from lethal cambium damage, raking the duff away from the bases of these trees before burning (within 24" of the bole and down to mineral soil) is recommended.

Considerations for hazard trees

Identification and removal of hazard trees within the project area should consider the type of target that may be impacted by a tree failure. Targets such as lower use Forest Service system roads may not require the same level of hazard tree removal as high use, paved county roads or adjacent private property, including structures. The Region 5 hazard tree guidelines (Angwin et al 2012) provide information to help land managers determine what type of hazard trees should be addressed and specific criteria for identification. The use of these guidelines is highly recommended for the Trapper project. Forest Health Protection can also assist with hazard tree field training for marking crews.

Potential for funding through the Western Bark Beetle Program

Forest Health Protection may be able to assist with funding for thinning and removing green material from overstocked areas within the Trapper project area. Thinning treatments that reduce stand density sufficient to lower the risk to bark beetle-caused mortality would meet the minimum requirements for Western Bark Beetle Program funding and would be supported by this evaluation. If you are interested in this competitive funding, please contact me for assistance in developing and submitting a proposal.

If you have any questions regarding this report and/or need additional information, please contact me at 530-252-6431.

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Insect and Disease Information

Western Pine Beetle

The western pine beetle, *Dendroctonus brevicomis*, has been intensively studied and has proven to be an important factor in the ecology and management of ponderosa pine throughout the range of the host species (Miller and Keen 1960). This insect breeds in the main bole of living ponderosa pine larger than about 8 inches DBH. Normally it breeds in trees weakened by drought, overstocking, root disease, dwarf mistletoe or fire. Adult beetles emerge and attack trees continuously from spring through fall. Depending on the latitude and elevation, there can be from one to four generations per year.

Evidence of Attack

Initial attacks are made about mid-bole and subsequent attacks fill in above and below. Pitch tubes are formed on the tree trunk around the entry holes. Successful pitch tubes are red-brown masses of resin and boring dust. Relatively few, widely scattered white pitch tubes usually indicate that the attacks were not successful and that the tree should survive. Pheromones released during a successful attack attract other conspecifics. Attracted beetles may then spill over into nearby apparently healthy trees and overwhelm the tree with sheer numbers.

Life Stages and Development

These beetles pass through the egg, larval, pupal and adult stages during a life cycle that varies in length dependent primarily on temperature. Adults bore a sinuous gallery pattern in the phloem and the female lays eggs in niches along the sides of the gallery. The larvae are small white grubs that first feed in the phloem then mine into the middle bark where they complete most of their development. Bluestain fungi inoculates the tree during successful attacks, blocking trachids and vessicles which contribute to the rapid tree mortality associated with bark beetle attacks.

Conditions affecting Outbreaks

Outbreaks of western pine beetle have been observed, and surveys made, in pine regions of the West since 1899 (Hopkins 1899; cited in Miller and Keen 1960). An insect survey completed in 1917 in northern California indicated that over 25 million board feet of pine timber had been killed by bark beetles. Information from surveys conducted in the 1930's indicated enormous losses attributed to the western pine beetle around that time. During the 1930's outbreak, most of the mortality occurred in stands of mature or overmature trees of poor vigor (Miller and Keen 1960). Group kills do not typically continue to increase in size through successive beetle generation as is typical with Mountain Pine Beetle and Jeffrey Pine Beetle. Rather, observations indicate that emerging beetles tend to leave the group kill area to initiate new attacks elsewhere.

The availability of suitable host material is a key condition influencing western pine beetle outbreaks. In northeastern California, drought stress may be the key condition influencing western pine beetle outbreaks. When healthy trees undergo a sudden and severe moisture stress populations of western pine beetle are likely to increase. Healthy trees ordinarily produce abundant resin, which pitch out attacking beetles, but when deprived of moisture, stressed trees cannot produce sufficient resin to resist the attack. Any condition that results in excessive demand for moisture, such as inter-tree competition, competing vegetation, or protracted drought periods; or any condition that reduces the ability of the roots to supply water to the tree, such as mechanical damage, root disease or soil compaction, can cause moisture stress and increase susceptibility to attack by the western pine beetle. Woodpeckers, predacious beetles, and low temperatures act as natural control agents when beetle populations are low (endemic populations).

Fir Engraver

The fir engraver attacks red and white fir in California. Fir engraver adults and developing broods kill true firs by mining the cambium, phloem, and outer sapwood of the bole, thereby girdling the tree. Trees greater than 4" in diameter are attacked and often killed in a single season. Many trees, weakened through successive attacks, die slowly over a period of years. Others may survive attack as evidenced by old spike-topped fir and trees with individual branch mortality. Although many other species of bark beetles cannot develop successful broods without killing the tree, the fir engraver beetle is able to attack and establish broods when only a portion of the cambium area has been killed.

Evidence of Attack

Fir engravers bore entrance holes along the main stem, usually in areas that are > 4" in diameter. Reddish-brown or white boring dust may be seen along the trunk in bark crevices and in spider webs. Some pitch streamers may be indicative of fir engraver attacks; however, true firs are known to stream pitch for various reasons and there is not clear evidence that pitch streamers indicate subsequent tree mortality or successful attack. Resin canals and pockets in the cortex of the bark are part of the tree's defense mechanism. Beetle galleries that contact these structures almost always fail to produce larval galleries as the adults invariably abandon the attack. Pitch tubes, often formed when bark beetles attack pine, are not produced on firs.

Adults excavate horizontal galleries that engrave the sapwood; the larval galleries extend at right angles along the grain. Attacks in the crown may girdle branches resulting in individual branch mortality or "flagging". Numerous attacks over part or the entire bole may kill the upper portion of the crown or the entire tree. A healthy tree can recover if sufficient areas of cambium remain and top-killed trees can produce new leaders. The fir engraver is frequently associated with the roundheaded fir borer and the fir flatheaded borer.

Life Stages and Development

In the summer, adults emerge and attack new host trees. The female enters the tree first followed by the male. Eggs are laid in niches on either side of the gallery. Adult beetles carry the brown staining fungi, *Trichosporium symbioticum*, into the tree that causes a yellowish-brown discoloration around the gallery. The larvae mine straight up and down, perpendicular to the egg gallery. Winter is commonly spent in the larval stage, with pupation occurring in early spring. In most locations, the fir engraver completes its life cycle in 1 year, however at higher elevations 2 years may be required.

Conditions Affecting Outbreaks

Fir engravers bore into any member of the host species on which they land but establish successful galleries only in those that have little or no resistance to attack. Populations of less aggressive species like fir engraver are likely to wax and wane in direct relationship to the stresses of their hosts. Drought conditions often result in widespread fir mortality; however, attempting to determine when outbreaks will occur is difficult. Lowered resistance of trees appears to be a contributing factor. Overstocking and the increased presence of fir on sites that were once occupied by pine species may also contribute to higher than normal levels of fir mortality. Several insect predators, parasites and woodpeckers are commonly associated with the fir engraver and may help in control of populations at endemic levels.

Mountain pine beetle

The mountain pine beetle, *Dendroctonus ponderosae*, attacks the bole of ponderosa, lodgepole, sugar and western white pines larger than about 8 inches dbh. Extensive infestations have occurred in mature lodgepole pine forests. Group killing often occurs in mature forests and young overstocked stands of ponderosa, sugar and western white pines.

Evidence of Attack

The first sign of beetle-caused mortality is generally discolored foliage. The mountain pine beetle begins attacking most pine species on the lower 15 feet of the bole. Examination of infested trees usually reveals the presence of pitch tubes. Pitch tubes on successfully infested trees are pink to dark red masses of resin mixed with boring dust. Creamy, white pitch tubes indicate that the tree was able to "pitch out" the beetle and the attack was not successful. In addition to pitch tubes, successfully infested trees will have dry boring dust in the bark crevices and around the base of the tree. Attacking beetles carry the spores of blue-staining fungi which develop and spread throughout the sapwood interrupting the flow of water to the crown. The fungi also reduces the flow of pitch in the tree, thus aiding the beetles in overcoming the tree. The combined action of both beetles and fungi causes the needles to discolor and the tree to die.

Life Stages and Development

The beetle develops through four stages: egg, larva, pupa and adult. The life cycle of the mountain pine beetle varies considerably over its range. One generation per year is typical, with attacks occurring from late June through August. Two generations per year may develop in low elevation sugar pine. Females making their first attacks release aggregating pheromones. These pheromones attract males and other females until a mass attack overcomes the tree. The adults bore long, vertical, egg galleries and lay eggs in niches along the sides of the gallery. The larvae feed in mines perpendicular to the main gallery and construct small pupal cells at the end of these mines where they pupate and transform into adults.

Conditions Affecting Outbreaks

The food supply regulates populations of the beetle. In lodgepole pine, it appears that the beetles select larger trees with thick phloem, however the relationship between beetle populations and phloem thickness in other hosts has not been established. A copious pitch flow from the pines can prevent successful attack. The number of beetles, the characteristics of the tree, and the weather affect the tree's ability to produce enough resin to resist attack. Other factors affecting the abundance of the mountain pine beetle include nematodes, woodpeckers, and predaceous and parasitic insects. As stand susceptibility to the beetle increases because of age, overstocking, diseases or drought, the effectiveness of natural control decreases and pine mortality increases.

Heterobasidion Root Disease

Heterobasidion spp. is a fungus that attacks a wide variety of woody plants. All western conifer species are susceptible. Madrone (*Arbutus menziesii*), and a few brush species (*Arctostaphylos spp.* and *Artemisia tridentata*) are occasional hosts. Other hardwood species are apparently not infected. The disease has been reported on all National Forests in California, with incidence particularly high on true fir in northern California, in the eastside pine type forests, and in southern California recreation areas.

Heterobasidion root disease is one of the most important conifer diseases in Region 5. Current estimates are that the disease infests about 2 million acres of commercial forestland in California, resulting in an annual volume loss of 19 million cubic feet. Other potential impacts of the disease include: increased susceptibility of infected trees to attack by bark beetles, mortality of infected trees presently on the site, the loss of the site for future production, and depletion of vegetative cover and increased probability of tree failure and hazard in recreation areas.

During periods favorable to the fungus, fruiting bodies (conks) form in decayed stumps, under the bark of dead trees, or under the duff at the root collar. New infection centers are initiated when airborne spores produced by the conks land and grow on freshly cut stump surfaces. Infection in true fir may also occur through fire and mechanical wounds, or occasionally, through roots of stumps in the absence of surface colonization. From the infected stump surface, the fungus grows down into the roots and then spreads via root-to-root contact to adjacent live trees, resulting in the formation of large disease centers. These infection centers may continue to enlarge until they reach barriers, such as openings in the stand or groups of resistant plants. In pines, the fungus grows through root cambial tissue to the root crown where it girdles and kills the tree. In true fir and other non-resinous species, the fungus sometimes kills trees, but more frequently is confined to the heartwood and inner sapwood of the larger roots. It then eventually extends into the heartwood of the lower trunk and causes chronic decay and growth loss.

Heterobasidion root disease in western North America is caused by two species: *Heterobasidion occidentale* (also called the 'S' type) and *H. irregulare* (also called the 'P' type). These two species of *Heterobasidion* have major differences in host specificity. *H. irregulare* ('P' type) is pathogenic on ponderosa pine, Jeffrey pine, sugar pine, Coulter pine, incense cedar, western juniper, pinyon, and manzanita. *H. occidentale* ('S' type) is pathogenic on true fir, spruce and giant sequoia. This host specificity is not apparent in isolates from stumps; with *H. occidentale* being recovered from both pine and true fir stumps. These data suggest that infection of host trees is specific, but saprophytic colonization of stumps is not. The fungus may survive in infected roots or stumps for many years. Young conifers established near these stumps often die shortly after their roots contact infected roots in the soil.

White pine blister rust

White pine blister rust is caused by *Cronartium ribicola* an obligate parasite that attacks 5-needled pines and several species of *Ribes* spp. The fungus needs the two alternate hosts to survive, spending part of its life on 5-needled pines and the other on *Ribes* spp. The disease occurs throughout the range of sugar pine to the southern Sierra Nevada, but has not been reported further south. Infection of pines results in cankers on branches and main stems, branch mortality, top kill, and tree mortality.

Spores (aeciospores) produced by the fungus in the spring on pine bole or branch cankers are wind-disseminated to *Ribes* spp. where they infect the leaves. Spores (urediospores) produced in orange pustules on the underside of the leaves reinfect other *Ribes* spp. throughout the summer, resulting in an intensification of the rust. A telial spore stage forms on *Ribes* spp. leaves in the fall. Teliospores germinate in place to produce spores (sporidia) which are wind-disseminated to pines and infect current year needles. Following infection, the fungus grows from the needle into the branch and forms a canker. After 2 or 3 years, spores are produced on the cankers and are spread to *Ribes* spp. to continue the cycle. Although blister rust may spread hundreds of miles from pines to *Ribes* spp., its spread from *Ribes* spp. back to pines is usually limited to a few hundred feet.

Branch cankers continue to enlarge as the fungus invades additional tissues and moves toward the bole. Branch cankers within 24 inches of the bole will eventually form bole cankers. Bole cankers result in girdling and death of the tree above the canker. Cankers that have margins more than 24 inches from the main bole are unlikely to reach the bole and only branch flagging will result.